OFFICE OF NAVAL RESEARCH

Geography Branch

FINAL REPORT

SUBJECT:

Interpretation of Glacial Drift from Color Airphotos

INVESTIGATOR:

Erhard M. Winkler, Department of Geology,
University of Notre Dame, Notre Dame, Indiana

CONTRACT NONR-1623 (08)
PROJECT NR 387-024

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<u>ABSTRACT OF FINAL REPORT</u>: Three years of financial support produced the following four scientific communications:

The Detection of Radio-active Minerals with Infrared Aerial Photography

Interpretation of Glacial Drift from Infrared Films

Relationship of Airphoto Tone Control and Moisture Content in Glacial Soils

Lineaments in Glacial Drift

An improved version of the third paper and the completed manuscript of the fourth paper are included in the final report as the information of the third paper is only limited and the manuscript of the fourth paper may not be published within the next year. Four commercial aerial films were used and the acquired experience is briefly discussed.

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Many test strips were flown with the purpose of geologically evaluating the four available commercial aerial films. All film material was photographed and developed under strictly controlled conditions by the investigator himself. The following film-filter combinations were applied:

1. Aerographic Super XX black-and-white roll film: a panchromatic film with a range covering the spectrum of visible light (4-7 micron). The standard haze filter (light yellow, Wratten K-2) showed better details and more contrast than pictures taken without a filter. Deep yellow and red filters barely marked an improvement against the K-2 filter. This film appeared to be best-suited to reproduce good contrasts of soil tones and soil moistures, as soil tone and terrain relief give both geologist and soil engineer information on the possible composition and origin of the drift. In areas of simple drift stratigraphy, groundwater conditions may be estimated.

2. Ektachrome Aero positive transparency color film: a highly variable color film despite the use of color correction filters. Colorimetric studies were not performed and are not recommended with this film. Color separation during printing may be successful in rock outcrops; however, little was achieved in mottled till.

3. Aerographic infrared black-and-white aerial film: the film is similar to Aerographic Super XX except for additional sensitivity into the near-infrared part of the light spectrum (4-9 micron). Infrared radiation may be made visible on the picture if yellow, red or deep red filters screen out at least part of the visible light. A light yellow haze filter (Wratten K-2) is best-suited to show soil tone contrasts. The forester prefers a light yellow filter for easier distinction of tree species on the basis of infrared radiation absorption. The high sensitivity to soil moisture formerly claimed proved to be incorrect as the film is less sensitive to soil moisture than Aerographic Super XX. Still unexplained are deviations of this film from Aerographic Super XX of old river sand bars through a thin snow cover. The use of this film is not recommended for general soil studies.

4. Ektachrome Aero Camouflage Detection (Infrared Color) film: it is basically an Aero-Ektachrome film with the magenta layer replaced with an infrared sensitive. With the Kodak recommended deep yellow filter (Wratten 15) living foliation appears deep red as this film is sensitive to chlorophyll. Camouflage green paint and dead grass of bare soil will appear in green or brown color, organic soil and muck deep black. The mottled soil pattern of morainal till is, therefore, in good contrast and clear on this film. The bare soil color on air photos was mostly green, sometimes brown; close-ups of soil pictures were always brown. The film is unable to penetrate either vegetation or the top soil, neither is the film sensitive to

moderate radiation of any kind. This film may be well-suited to soil mapping if the color inconsistency can be technically overcome. None of the four aerial films penetrate the top soil nor the vegetation cover.

The following six test strips with glacial debris cover were flown at the scale five inches to the mile at different seasons of the year: late April, before the vegetation on the fields covered the bare soil; late in summer; in fall during climax and post-climax of discolored foliage; through a thin snow cover in winter.

1. South Bend strip, about three miles north of town, east-west strip ten miles long and two miles wide. The strip covers the Outer Kalamazoo Moraine (Maxinkuckee Moraine), pitted outwash, Inner Kalamazoo Moraine, valley train. Results: the mottled soil pattern was observed of equal contrast for both the moraine and the pitted outwash. Field work showed that the darker soil tone is the result of the accumulation of organic substance in even shallow depressions; the accumulation of fine soil particles also may contribute to darker soil tones. Silt and clay is easily washed down into adjacent depressions. Reliefs of only a few inches were sufficient to see the difference in the grain size distribution. The mottled morainal topography show up best on airphotos taken with Kodak Super XX film. Ektachrome Aero film and Ektachrome Aero Camouflage Detection film were critically compared and small test areas printed through a variety of color filters onto panchromatic Kodak Panalure paper. The comparison of quantitative densitometric profiles did not reveal additional features which were obscured on the original airphotos.

2. Grand Marais dunes and Lake Michigan terraces: No results could be observed in this area.

3. Airphoto mosaics in northwestern Indiana: Francesville, Monon, Kentland, Remington. Report No. 2, Airphoto Lineaments in Glacial Drift of Northwestern Indiana, which is included, gives a detailed geologic account of this area.

Four scientific communications developed under the sponsorship of the Office of Naval Research.

1. The detection of radio-active minerals with infrared aerial photography: Economic Geology, v. 56, p. 211-214, 1961 (with Barry Voight).

2. Interpretation of glacial drift from infrared films: Presented at the Society of Photogrammetry 26th Annual Meeting, Washington, D. C., 24 March 1960. Also published in Photogrammetric Engineering, v. XXVI, no. 5, p. 773, 1960.

3. Relationship of airphoto tone control and moisture content in glacial soils: Presented at Symposium on Remote Sensing, University of Michigan, 15 October 1962.

4. Airphoto lineaments in glacial drift of northwestern Indiana: manuscript completed, to be published soon.

Communication Nos. 1 and 2 were distributed as Technical Reports; therefore, the abstracts of these first two papers are included here. Communication Nos. 3 and 4 are included unabridged as they have not been distributed.

ABSTRACT FOR COMMUNICATION NO. 1: The detection of radio-active minerals with infrared aerial photography.

Claims were made (Laylander) that Ektachrome-Aero Camouflage Detection film is sensitive to radiation and could be successfully used in the survey of uranium-producing areas of the Colorado Plateau. The alleged sensitivity to radiation of four commercial aerial films was tested by exposure in the laboratory to the following highly radio-active substances: pitchblende, carnotite, U_3O_8 concentrate, and 5 mg. of radium. None of the films showed traces of radiation as markings or clouding. Laylander's claims are disproved; the Camouflage Detection film may have recorded other features than radiation.

ABSTRACT FOR COMMUNICATION NO. 2: Interpretation of glacial drift from infrared films.

Transmission densitometer profiles were studied of a few test areas from vertical airphotos. The profiles showed some inconsistencies across elevated stream terraces between the Super XX Aerographic film and the Infrared Aerographic black-and-white films. No geologic explanation is presently available for this difference.

MOISTURE MEASUREMENTS IN GLACIAL SOILS FROM AIRPHOTOS

Erhard M. Winkler
University of Notre Dame

ABSTRACT: Experiments were conducted on the ground with glacial soils at different water contents. The relationship between the tone of airphotos and the water content of soils was established with four commercial aerial films. The densities of the developed films were measured on the negatives with a standard Weston Photographic Analyzer. The film densities rose approximately proportional to the moisture contents up to near the Atterberg Plastic Limit of the soil, but again sharply decreased towards the Atterberg Liquid Limit. Results obtained from ground experiments did not quite match the density-moisture proportions from actual airphotos, which are believed to exist.

The mottled pattern of morainal topography on airphotos is well-known to glacial geologists and soil scientists. The field evidence points to darker tones for the lower places of the terrain and lighter tones for knobs and ridges. The reason for this difference in tone is the subject of this paper.

Soil surfaces reflect solar radiation which may be seen by the human eye and may also be recorded on photographic emulsions. Most panchromatic films record wave lengths between 4-8 micron whereas the sensitivity of infrared emulsions usually starts in the red and carries on to about 9 micron. Standard camera equipment is applicable only for the 4-9 micron range. More sophisticated sensors permit sensitivities to or beyond 25 micron; e.g., the Barnes Far Infrared Camera; the infrared radiation is "translated" by sensor tubes into the visible portion of the spectrum. The work of the present author is restricted only to commercial photographic emulsions which should determine the quantitative relationship between the soil moisture and the tone intensity. A prediction of the soil moisture content from airphotos is of great interest to agronomists, groundwater geologists, and to military agencies for the determination of the general trafficability for heavy moving equipment and for safe aircraft landing sites.

The gray soil tones recorded on panchromatic films depend on the following variables: the original soil color of the glacial drift, the moisture content of the soil and the amount of the organic matter of the soil; these combine to produce the soil tone. Light soil tones generally characterize well-drained coarser grained soils, darker tones finer soils with a higher retaining capacity for water along the smaller capillaria. Morainal kettles, therefore, show a higher accumulation of water than knobs do. This accumulation of fine particles is suggested to be of colluvial origin from the knobs. Frey, Glass, and Willman (1960) demonstrate with the help of clay

mineralogy that the fine soil accumulation in glacial depressions have not developed a weathering profile yet which proves the youthful origin. The process of colluviation may cause a considerable difference in the grain size distribution from high to low points according to numerous grain size analyses which were performed by the author across the Valparaiso Moraine of southwestern Michigan. Often soils from knobs are so coarse grained that they resemble sandy gravel. The process of colluviation was also observed in shallow pitted outwash. A mottled soil pattern should be expected across both till moraines and in pitted outwash.

Krinov's classical study (1947) of the spectral reflectance of natural formations includes the reflectance curves for dry and wet soils, and boulder fields across the spectrum. From his curves the spectral reflectance shows a clear difference between dry and wet soils--higher reflectance for dry soils and lower reflectance for wet soils; this gap widens in the near-infrared part of the spectrum. Krinov did not extend his measurements into the far-infrared part of the spectrum. The present author assumed on the basis of Krinov's findings that infrared sensitive photographic emulsions should clearly record the difference between dry and wet soils if wave lengths shorter than red are cut off with the proper filters. The theoretical basis seemed to be given for recording soil moisture contents from airphotos.

The determination of the soil moisture content from the soil tone was already attempted by O'Neal (1923). He estimated the water content of the soil by comparison of the soil samples with color tone charts which were set up for each soil under investigation. O'Neal claims good accuracy. No important reference is available until 1955 when Altschaeffl tried to estimate the moisture content from airphoto tones of glacial drift of the Valparaiso Moraine near LaPorte, Indiana in an unpublished master's thesis. Altschaeffl claims good correlation between the moisture content of the soil in the field and the tone of the airphoto negative. The deviation from the true moisture content in the field, however, was sometimes more than 100 percent. The relationship of film densities and soil moisture contents was also studied by the United States Armed Forces; these reports are classified or inaccessible to the public otherwise. Other reports talk about different approaches to this subject without discussing the subject matter itself. Most of this work refers to research done with sensors in the far-infrared part of the spectrum or with radar images. Spectrometers and sensors are beyond the scope of this paper. The author's work merely extends to the 4-9 micron range.

A series of ground experiments was performed with the purpose to seek a quantitative relationship between the soil moisture and the tone of the airphotos. The soil samples were cleaned of stones larger than 2 mm., applied wet into Petri dish halves, and subsequently dried to the desired water content. Each

soil type was photographed at three to four different water contents on one single picture: one sample near the Atterberg Plastic Limit, one near the Atterberg Liquid Limit, one somewhere between the Plastic Limit and airdried state and a fourth sample in airdried condition. The samples were placed on a Kodak Neutral Gray Card with a light reflectance of 18 percent on the gray side. The camera was a vertically set-up Voigtlaender sheet film camera 9 x 12 cm. format which photographed the samples about three feet above the object. Commercial aerial films were cut from film rolls to sheet film size and exposed in rapid sequence through the factory recommended filters; this fast action avoided undesirable changes of the water content between the time the films were exposed and the moisture content determined immediately after the pictures were taken. The following film-filter combinations were applied: Kodak Super XX Aerographic with a minus-blue filter; light yellow, Wratten K-2; Kodak Aerographic Infrared with a red filter, Wratten 25, A; Kodak Ektachrome Aero, no filter; Kodak Ektachrome Aero Camouflage Detection or infrared color, deep yellow filter, Wratten 15, G. Additional experiments were made with Kodak Ortho-Press sheet film to study filter efficiencies. All films were developed by the investigator himself under identical darkroom conditions; this minimized discrepancies between each set of experiments. The exposure control of the infrared sensitive films raised problems as standard exposure meters do not properly record infrared radiation. Positive transparencies record the tones as they are, film negatives reverse the soil tones. The film densities were recorded with a Weston Photographic Analyzer (photographic transmission densitometer) which records film densities from 0, transparent, to 3, opaque. A light beam of constant intensity is transmitted through a pinhole of 1 mm. diameter onto an exposure meter. A meter dial records the results in meter-candles ranging from 0-650; the density values are inversely proportional to the meter-candle readings. Four histograms of the tone-moisture content relationship for four different commercial film emulsions are presented and discussed, with the densities on the abscicca and the water contents on the ordinate axis. Density values were also recorded with the transmission densitometer from photos of field plots on single weight photographic printing paper after treatment of the prints with mineral oil for better light transmission. All densities of the ground experiments were measured off the negatives directly in order to avoid additional density fluctuations caused by the prints.

The following soils and mineral aggregates were used in the ground experiments:

1. Glacial till, Valparaiso Moraine, from an adjacent knob and kettle, seven miles west of Dowagiac, Michigan.

2a. Glacial till, Valparaiso Moraine, one mile west of Galien, Michigan. Results are not pictured here as this soil was only used in preliminary experiments.

2. Organic silt from the flood plain of the St. Joseph River, northeast of Berrien Springs, Michigan. The silt is finer and darker along the ridge tops than in the shallow depressions; these are probably mud levees.

3. Outwash sand from pitted outwash plain of adjacent high and low spots in the terrain. Two miles southwest of Dowagiac, Michigan.

4. Muck soil, black. Two miles west of Dowagiac, Michigan.

5. Kaolinite, Dry Branch, Georgia.

6. Bentonite, activated montmorillonite clay, Wyoming. The results are not pictured here as this mineral was only used in preliminary experiments.

The illustrations compare five different soils on four commercial aerial films. All soils except the Georgia Kaolin show a strong density decrease on the film negative, respectively increase on positive film emulsions with increasing moisture content. The tone increases about proportional to the moisture content to near the Atterberg Plastic Limit, but falls off to less density again beyond the Plastic Limit towards the Atterberg Liquid Limit. The density of the Neutral Gray Card below the soil samples offers a good point of reference to the water content-density curves; this permits absolute figures for comparing both the dry soil densities and also the wet soil densities with each other, regardless of differences of the film exposure or film development.

A clear distinction of dry soil tones is evident between the till from the knob and from the kettle; the high till also shows a greater density increase with increasing moisture content than the low terrain till does; the diminished silt and clay content of the high terrain till may cause this contrast. In the field, the contrast of the mottling on airphotos lessens with increasing moisture content. A more prominent density increase is observed with the river silt from the levee tops as against the low places between the levees. The tone of the dry silt, however, is lighter between the levees than on the levee tops. The sands of the pitted outwash show equal density increases with rising moisture content for both high and low terrain sand, although the high sand is much lighter in tone than the low sand.

The curves of the soils which were photographed with Aerographic Infrared black-and-white film (Illustration 2) compare well with those photographed with Super XX Aerographic black-and-white film. Less intensive reflection of the infrared radiation, however, allows the negatives to appear denser for the soils in reference to the underlying Kodak Neutral Gray Card. The tone contrasts of the high and the low terrain soils are about equal for both emulsions.

The sensitivity for changing moisture contents, however, is better on the Super XX Aerographic film for all the soils tested.

The contrasty positive Ektachrome-Aero film (positive color) (Illustration 3) compares well with the densities shown on Super XX Aerographic film in respect to both dry soil densities and density-water content proportions. No colorimetric methods were applied to the two color films.

The soil light reflection recorded on the Ektachrome Aero Camouflage Detection film is about similar to the Aerographic Infrared film. This film is basically an Ektachrome Aero film with an infrared sensitive layer replacing magenta; living foliage is red, bare soil green or brown. The moisture sensitivity is much higher than on all the other films. The deep red of living foliage and the black of moist mucky fields cause a beautiful color contrast for this film.

The following table compares the tonal difference of the dry soils with the Neutral Gray Card; the table also includes the density difference between the dry and the moist soil near the Atterberg Plastic Limit: these values are only approximations as the second point is just near the moisture content of the Plastic Limit. All values were scaled off the curves. The last column of the table lists the amount of the fine soil fractions which still passes through a 0.1 mm. sieve, expressed in percent of the total weight of the dry soil.

SOILS	Dry soil difference with tone of Gray Card				Density difference between dry soil and Plastic Limit				Silt & Clay in percent
FILMS	XX	IR	AE	CD	XX	IR	AE	CD	
till, high	.18	.29	.14	.58	.66	.40	.48	.76	38
till, low	.11	.09	.06	.43	.46	.23	.47	.76	77
silt, high	.05	.38	.16	.01	.43	.38	.51	.40	92
silt, low	.13	.12	.06	.14	.30	.05	.35	.21	69
sand, high	.13	.38	.01	-	.25	.39	.82	-	14
sand, low	.08	.19	.22	-	.43	.43	.54	-	26
muck soil	.50	.05	.15	.40	.50	.45	.54	.81	-
kaolin	.76	.69	.76	.51	.22	.17	.09	.20	-

Explanation of the abbreviations:

XX - Aerographic Super XX
IR - Aerographic Infrared
AE - Ektachrome Aero
CD - Camouflage Detection

EVALUATION OF THE RESULTS AND CONCLUSION: The occurrence of the water in the soil should be well understood and will be, therefore, briefly explained here. There are three different types of water in the soils:

1. Water absorbed as crystal water; it is introduced during the weathering process and is part of the crystal thereafter. This water is neither visible nor does it influence the physical properties of the soil; e.g., plasticity. The presence of the highly absorbent mineral montmorillonite may cause the absorption of large quantities of water; the density-moisture content curve for montmorillonite which is not pictured here shows very little fluctuation of the tone for water contents between 10 and 150 percent. Crystal water is not expected to influence the soil tone.

2. Water absorbed to the crystal surface; it adheres to the soil grain and is firmly held as a thin film around the tiny clay crystal. The thickness of this water film depends on the absorptive power of the mineral grain. It is believed that only a small part of the absorbed water may influence the soil tone.

3. Capillary water; it fills the pores and channelways between the mineral grains; this type of water is believed to be the most important controlling factor of the soil tone.

It is evident from the curves that the lighter colored soils of the topographic higher terrain are more sensitive to tone changes with higher moisture content than the darker and finer soils of adjacent depressions. The increase of the density is approximately in proportion to the increasing soil moisture to near the Atterberg Plastic Limit of the soil; a further increase of the moisture decreases the density rapidly again. Excess water in the soil capillaria near the Atterberg Liquid Limit may cause higher light reflection than the soil without water: the tone decreases again at very high water contents.

Infrared sensitive emulsions are less sensitive to moisture changes than standard panchromatic emulsions. This is a surprise to the author. He first assumed that, on the basis of infrared spectrograms, the contrast between dry and wet soil tones would be greater on infrared photographic emulsions as compared with panchromatic emulsions. The infrared color film (Camouflage Detection) shows a similar sensitivity to moisture as the infrared black-and-white film; the sensitivity of this film to moist mucky soil is exceptionally high.

The repetition of the ground model experiments did not yield similar results; deviations up to 50 percent of the first set of experiments are common. The human factor may be made responsible for this discrepancy.

The application of the foregoing ground experiments to actual vertical airphotos encountered difficulties: the process of soil drying of bare fields was not uniform. The drying of glacial till usually starts on the surface as a thin dry film which covers the wet soil below which results in an over-all tone neither

representing the dry nor the wet soil layer. Thus, some clayey soils do not permit estimations of moisture contents of field plots from airphotos during the drying process. The identification and comparison of dry soil densities of lighter colored soils from higher spots against darker soils from lower spots was more accurate than the interpretation of wet soils. A density comparison of the soils was attempted in the field whereby a mosaic of twelve Kodak Neutral Gray Cards measuring 8.5 x 11 inches each, was laid out in the field and photographed with the soil. But rapid warping of the cards under the influence of the sun from above and the effect of ground moisture from the soil below prevented accurate density comparisons from airphotos. Soil samples were taken from the test plots within about 30 minutes the airphoto was taken; the water content was subsequently determined in the laboratory. Dry soils only allowed good correlation of the airphoto densities with densities measured from films of the laboratory samples. The ground model experiments recorded a contrast twice to three times higher than the contrasts of the same soils in the field plot from airphotos. The author does not have an explanation for this discrepancy.

In conclusion, a good estimation of the moisture content from airphotos would be only possible if the tone of the air-dry soil is well-known in comparison with the Kodak Neutral Gray Card. The unequal drying process of the soil surfaces is the major obstacle for density correlation and moisture content estimates for glacial soils on the basis of film densities.

The soil tone is generally influenced by the following variables: original soil color, organic matter content, grain size distribution, average tone of an unevenly drying soil. The tone of the air-dried soil should be known in order to make the estimate of the approximate moisture content possible. The rapid change of dried soil tones in glaciated terrain makes the problem of the soil moisture determination more difficult as single commercial air-photos may record numerous soil tones. The commercial black-and-white film, Kodak Super XX Aerographic, is best-suited for the experiments because it is most sensitive to changes of the moisture content of soils.

An oral presentation of this paper was given at the Second Symposium on Remote Sensing of Environments held at the University of Michigan, Ann Arbor, Michigan, on 15 October 1962.

BIBLIOGRAPHY

Altschaeffl, G., 1955, Effect of soil moisture and other natural variables on aerial photo gray tones: Master's thesis, Purdue University, Lafayette, Ind.

Brown, P. E. and O'Neal, A. M., 1923, The color of soils in relation to organic matter content: Iowa Agr. Exp. Sta. Res. Bull. 75.

Frey, J. C., Willman, H. B. and Glass, H. D., 1960, Gumbotil, accretion-gley, and the weathering profile: Illinois State Geol. Survey Circ. 295.

Hackforth, H. L., 1960, Infrared Radiation: McGraw-Hill Book Co., Inc., New York.

Krinov, E. L., 1947, Spectral reflectance of natural formations: Laboratoriia Aerometodov, Akad. Nauk. SSSR, Moscow.

Photographic and photogrammetric methods of terrain analysis for determination of aircraft landing sites: Itek Corp., Palo Alto Div., Calif. Air Force Contract 19 (629) 277, Bedford, Mass., 1962.

O'Neal, A. M., 1923, The effect of soil moisture on soil color: Soil Science, v. 16, p. 275-279.

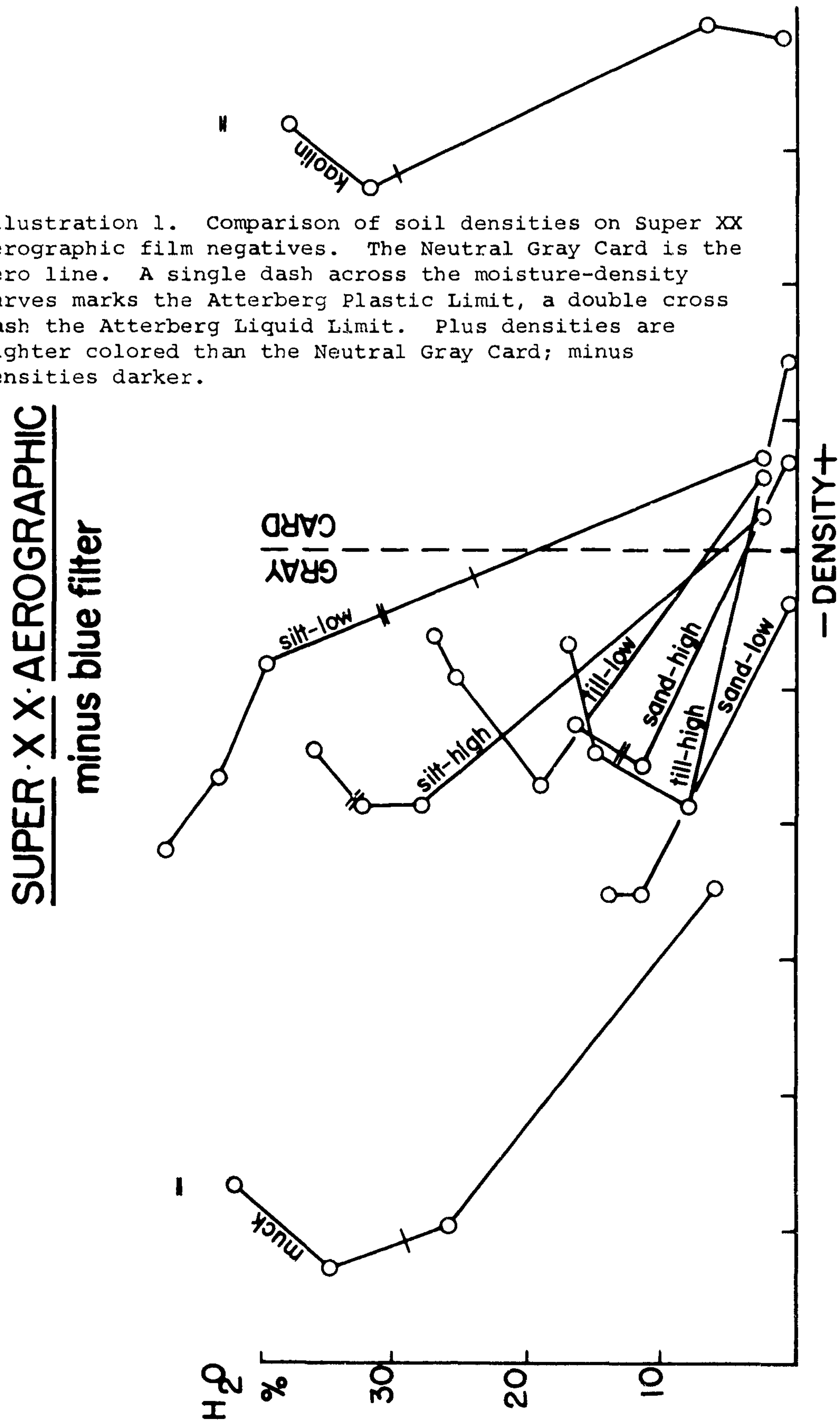


Illustration 1. Comparison of soil densities on Super XX Aerographic film negatives. The Neutral Gray Card is the zero line. A single dash across the moisture-density curves marks the Atterberg Plastic Limit, a double cross dash the Atterberg Liquid Limit. Plus densities are lighter colored than the Neutral Gray Card; minus densities darker.

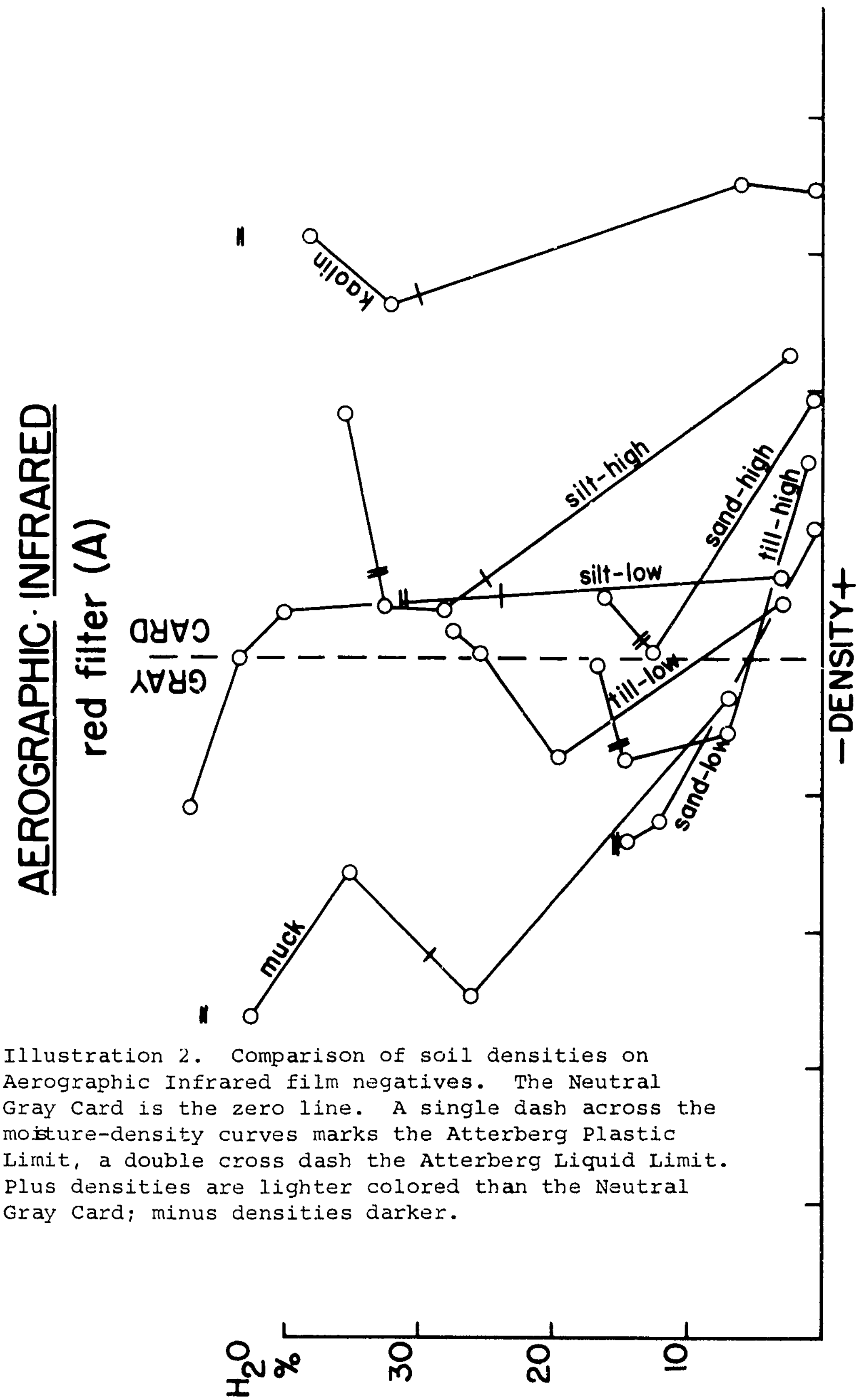


Illustration 2. Comparison of soil densities on Aerographic Infrared film negatives. The Neutral Gray Card is the zero line. A single dash across the moisture-density curves marks the Atterberg Plastic Limit, a double cross dash the Atterberg Liquid Limit. Plus densities are lighter colored than the Neutral Gray Card; minus densities darker.

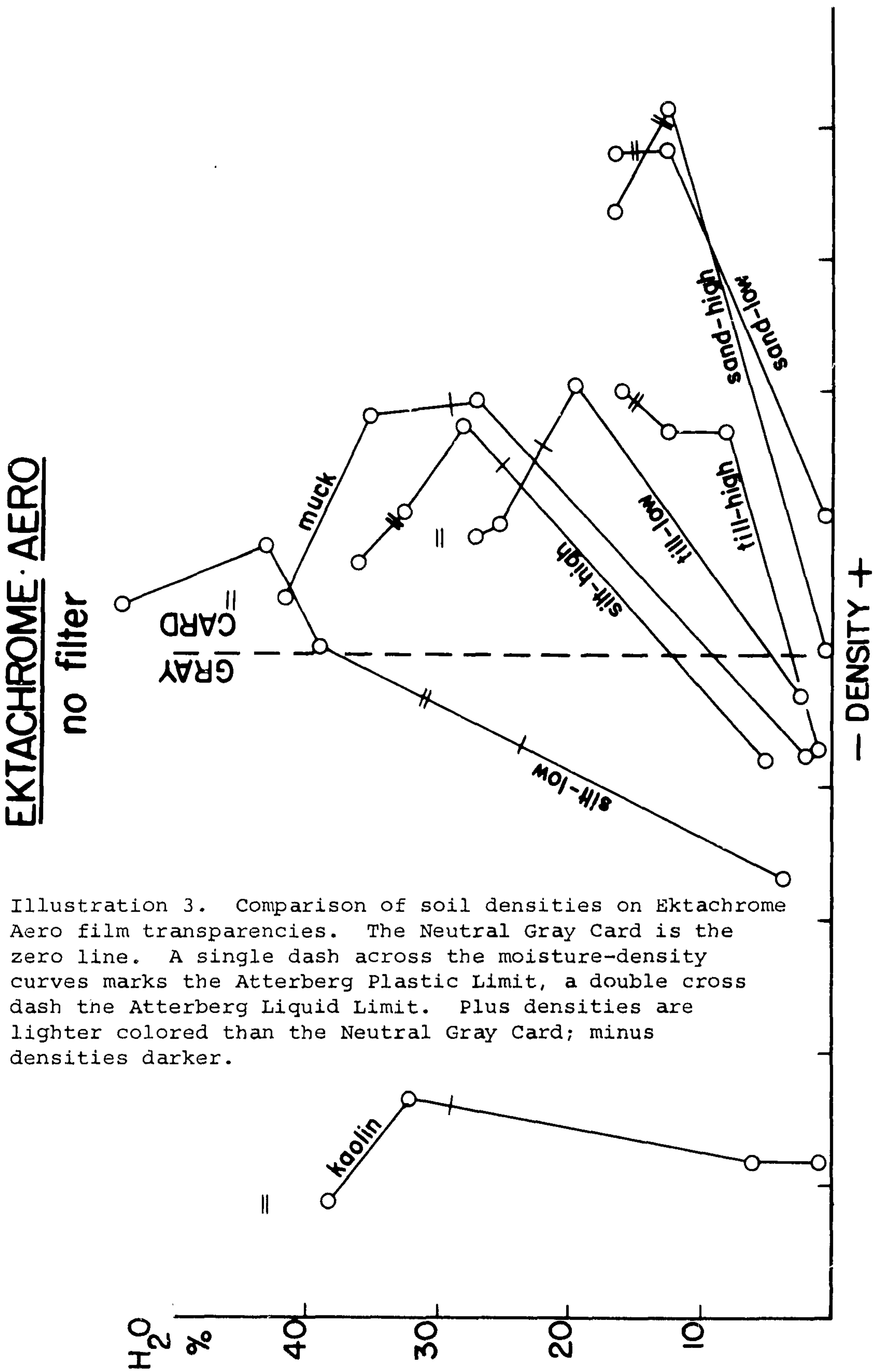


Illustration 3. Comparison of soil densities on Ektachrome Aero film transparencies. The Neutral Gray Card is the zero line. A single dash across the moisture-density curves marks the Atterberg Plastic Limit, a double cross dash the Atterberg Liquid Limit. Plus densities are lighter colored than the Neutral Gray Card; minus densities darker.

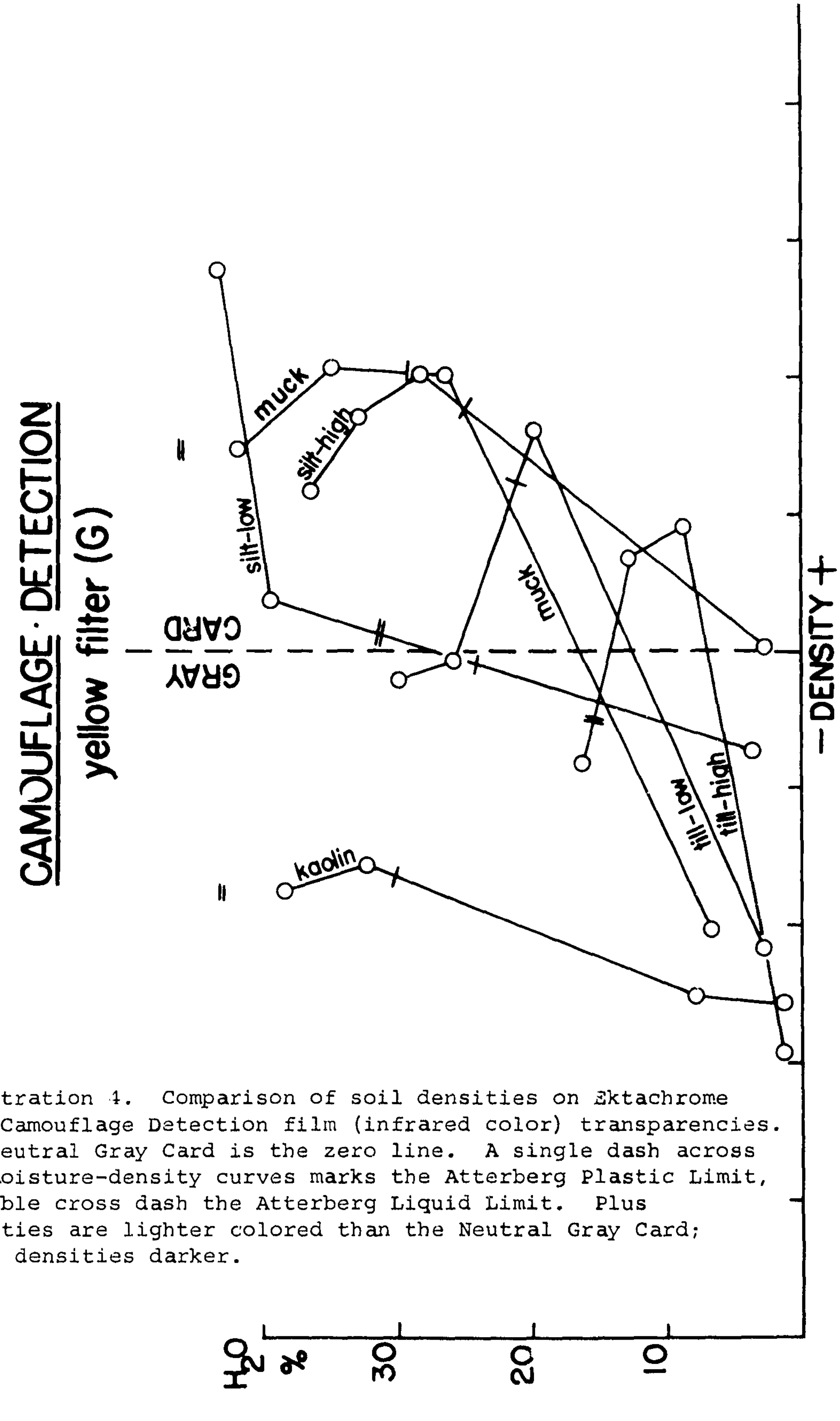


Illustration 4. Comparison of soil densities on Ektachrome Aero Camouflage Detection film (infrared color) transparencies. The Neutral Gray Card is the zero line. A single dash across the moisture-density curves marks the Atterberg Plastic Limit, a double cross dash the Atterberg Liquid Limit. Plus densities are lighter colored than the Neutral Gray Card; minus densities darker.

AIRPHOTO LINEAMENTS IN GLACIAL DRIFT OF NORTHWESTERN INDIANA

Erhard M. Winkler
University of Notre Dame

It is the objective of this paper to discuss light-colored lineaments and reevaluate dark-colored lineaments which the author saw on uncontrolled airphoto mosaics at the scale of five inches to one mile of some areas in ground morainal till of northwestern Indiana.

The pictures were flown in May 1960 and 1961 just before the start of the corn and soy bean growth. Airphotos which were flown later in the season did not disclose most of the lineaments as they were hidden below the crop cover. The following uncontrolled airphoto mosaics were prepared in a five-mile radius around well-defined rock outcrops.

Monon, White County, Indiana. Mosaic around the Monon Crushed Stone Quarry, a mid-Silurian (Niagaran) coral reef. Shallow till of the Cartersburg Till Plain of west-central Indiana overlies the rock at the quarry site, increasing its thickness quickly to about 50 feet away from the quarry according to McGrain's Drift Thickness Map of North-Central Indiana (1950). Low sand hills on till are common. There are some higher sand hills in the area which are covered with dense brush and are, therefore, not easily visible on the airphotos. Mucky ground between the low sand dunes increases the tone contrast with the light-colored sand, which is part of Wayne's (1963) late Pleistocene outwash and dune facies of the Atherton formation underlain by the Cartersburg till member of the Trafalgar formation of Tazewell substage.

Francesville, Pulaski County, Indiana. This mosaic is located about eight miles north of Monon around the Francesville Crushed Stone Quarry. Dolomite rock of mid-Silurian (Niagaran) age is quarried near the north edge of the center of the Kankakee Arch. Shallow drift surrounds the quarry falling off to a thickness of nearly 50 feet. Some very low sand dunes and dark organic soil patches between the sand give the appearance of a checkerboard topography. Lacustrine and outwash sediments with dunes of the Atherton formation of late Wisconsin age cover the area. These are underlain by the Cartersburg till member of the Trafalgar formation of Tazewell substage.

Remington, Jasper County, Indiana. The area is located about 25 miles southwest of Monon. Erosion resistant lower Pennsylvanian Mansfield sandstone is exposed as a stratigraphic outlier on upper Devonian New Albany shales in Fountain Park about one mile north northwest of Remington. The till of Cartersburg age is missing in and near Fountain Park and increases to a thickness of 30 feet east of Remington.

Kentland, Newton County, Indiana. The mosaic is centered around the Newton County Crushed Stone Quarry located in highly disturbed early Paleozoic rocks which are surrounded by much younger undisturbed lower Mississippian rocks. The till cover, also the Cartersburg member of Trafalgar formation, is only about 15 feet thick over the disturbed area but quickly reaches a thickness of 50 feet a few hundred feet away from the center of the quarry.

The following film-filter combinations were used for the mosaics: black-and-white (Kodak Aerographic Super XX) with a light yellow haze filter Kodak Wratten 12 and a red filter Kodak Wratten 25; black-and-white infrared film (Kodak Infrared Aerographic film) with a red Wratten 25 filter; aerial positive color roll film (Kodak Ektachrome Aero film) with a light yellow haze filter; infrared color film (Ektachrome Aero Camouflage Detection film) with a Kodak recommended deep yellow Wratten 15 filter. All airphotos were flown, developed and printed under controlled conditions by the author himself for especially high contrast effect. The author uses the word lineament for surficial alignments which are clearly visible on airphotos. Kupsch and Wild (1958) reject the frequently used term "....linears because this is an etymologically undesirable term, a plural noun formed from an adjective, which has also been employed in a different manner...." Some of these lineaments are darker lines in a lighter colored till; others are lighter toned features in a darker till environment. Both features are frequently found in ground morainal till plains. This paper primarily discusses the origin of light-colored but also takes the opportunity to reevaluate dark-colored lineaments. The following lineaments were observed on the available mosaics.

1. Dark depressed relief lineaments in lighter ground moraine. They are narrow lines surrounded by much lighter colored till which often appear on airphotos of recently plowed or tilled fields. The author suggests the term "negative relief lineament". Lattman (1958) points out that these darker lineaments are shallow depressions which have attracted more moisture in the poorly drained till; uneven compaction of bedrock below the till along a fault or shear zone are made responsible for the depression. These, Lattman claims, show up well on the more moisture sensitive infrared photographic emulsions. In contrast to Lattman's idea, the present author considers Pleistocene and post-Pleistocene compaction of underlying Devonian New Albany shales in the Remington mosaic area of negligible importance as the shales were well-compacted long before the till was laid down, both by geologic age and by Pennsylvanian Mansfield sandstones of probably considerable thickness. Remnants of these sandstones are still found in the area as small stratigraphic outliers, one of them in the Fountain Park area near Remington. Dark narrow lineaments in thin ground morainal till are ascribed in most instances to the scouring action of the moving ice before the till was laid down which cut deeper furrows along faults and shear zones than along sound rock surfaces. An even till blanket spread across the rock surface, a little thicker above the scoured weak zone. Subsequent general compaction of the till caused some more till consolidation over scoured shear zones

aided by better till drainage downward along disturbed rock zones. Darker soil tones on airphotos along minor linear depressions in till were not so much produced by the concentration of more water but rather by the accumulation of more organic substance producing much darker organic soil. Contrary to Lattman, infrared film does not show higher sensitivity to soil moisture; this film is rather less sensitive to soil moisture than the standard black-and-white films used with haze filters, according to experiments performed by the author (1963).

Kupsch and Wild (1958) describe large lineaments in till in the Avonlea area of Saskatchewan which they believe to follow inactive faults where temporary movements along the faults became active again by the uneven distribution of the ice load on the crust. These movements also affected the till surface directly leaving a small escarpment according to Barton (1962). Straight dark-colored lineaments may, therefore, easily develop along such minor till escarpments.

Three distinct directions of negative lineaments may be identified on the Remington mosaic along which present or former minor drainage follows. The one direction runs N. 56 W., the other N. 47 W., the third between N. 38 E. and N. 40 E. Fountain Creek also follows a straight line for about one-half mile through the sandstone in the Fountain Park Pennsylvanian stratigraphic outlier along the main joint direction N. 56 W. The sandstone outlier is not covered with till as it forms a minor topographic high in the area; the stream is considered a subsequent structure controlled stream within the sandstone outlier. This direction runs parallel to the axis of the Kankakee Arch 15 miles to the northeast of here; this may be just a coincidence. The negative relief drainage lineaments northeast southwest seem to reflect the former ice flow of the Saginaw ice lobe although ice striations on bedrock at the nearby Pleasant Ridge quarry is N. 12 E.

Neither N. 47 W. lineament nor N. 56 W. have shown near parallel rock striation in any one rock outcrop. It is, therefore, believed that the N. 47 W. lineaments in Cartersburg till of the Tazewell substage reflect a last ice advance of a thin ice sheet into this area which was too thin to strip the existing till but thick enough to cause oriented fluting and some oriented drainage which were observed by the author as shallow pools during a high altitude flight at about 8000 feet over this area after heavy rainfall. This ice direction was not recognized by Zumberge (1960) in his correlation of Wisconsin drift. Leighton (1959) describes similar straight shallow erosion troughs in Illinoian drift of southwestern Illinois. He found also primary ice crevasse channels near the erosion troughs which he ascribes to ice stagnancy. Crevasse channel fills and other similar features will be described in the following chapter on positive relief lineaments. The N. 56 W. lineament, however, may reflect rock structures like the jointing controlled Fountain Creek. Most of these lineaments occur in till over New Albany shale outside the sandstone

outlier. The author failed to find the N. 56 W. or any similar joint direction in the shales along Carpenter's Creek northwest of Fountain Park. The fractures in the shales are curved and the determination of their azimuths is, therefore, difficult in narrow outcrops. A different fracture pattern should be expected in shales than as in sandstones despite the fact that the rupturing of the rocks was caused by the same mechanical stresses of the Kankakee Arch.

2. Light raised relief lineaments in darker ground moraine. They are generally light-colored lineaments in coarser grained and better drained soil than the till around them. The author suggests the term "positive relief lineaments". Light-colored straight narrow lines are frequently found on the Monon mosaic; their azimuths vary between N. 79 W. and N. 81 W. Several of these lines end in a broader parabolic loop with the concave part facing west northwest. Some of these lineaments are a few miles long. Illustration 1 reproduces the Monon mosaic with the stone quarry in its center. The lineaments are longitudinal dunes with parabolic blow-out dunes at their ends. The average wind direction in this area was from the west northwest. Odum (1952) believes that high winds blew off the North American ice sheet to the southeast forming the Carolina Bays in North Carolina. Winds up to 100 miles per hour are forming the wind-oriented lakes of the Alaska Coastal Plains. Longitudinal dunes of this dimension must have required the presence of winds of similar intensity in northwestern Indiana; therefore, very strong dry winds blew off the high pressure area of the receding Lake Michigan ice lobe to the northwest picking up considerable quantities of fine sand from the Kankakee fluvial plains just a short distance to the west of Monon (Wayne's, 1963, Atherton formation of late Pleistocene age, forming longitudinal dunes of low relief). Some of the parabolic dunes are just low ridges three to five feet high with the east face a little steeper. Some others, however, are covered with dense brush and still show almost the original dune profile with slip faces measuring about 20 degrees. These dunes are undisturbed and were saved from many years of cultivation and exposure to winds from the southwest. The field observer may see several such parabolic dunes west of Monon, some already off the Monon mosaic. The dune sand is well-sorted and very fine on the parabolic dunes, but a little coarser along the longitudinal dunes; the rounding of the grains is very poor suggesting only a short distance of transportation.

No light-colored positive relief lineaments were observed in the area of Francesville. A few indistinct parabolic dunes are visible southwest of Francesville; their concave side faces southwest. These dunes are probably younger in age than the dunes described on the Monon mosaic as the chief wind direction had already shifted to the southwest after the complete disappearance of the ice sheet.

The Remington mosaic (Illustration 2) displays different sets of light-colored lines, some of them of considerable length and straightness. One set of lines is sharply defined, straight narrow, with occasional breaks of the direction with the general azimuth N. 30 W.

and sometimes end in a broad loop to the east. The reproduction of the mosaic caused the loss of many details on Illustration 2. On the ground the lineaments are barely visible ridges which are generally not higher than three to five feet above the terrain level. Several auger borings were dug across some of these low ridges east of Remington. The diagrams of Illustration 3 compare the grain size distribution of the sediments of the ridges at different depths as cumulative histograms. The profiles show that fine particles were moved downward towards the two-foot horizon in all sediments. The till-like sorting of the sediment on the lineaments compares with the well-oxidized debris of the ridges. The sediment at the bottom part of the ridge contains much calcareous material; so does the till below which is strongly compressed and dewatered. The till surface beneath the ridges was depressed about two to three feet below the terrain level. Electric resistivity profiles across the ridges mark a distinct break between the moister sediment of the ridge against the dryer till. The electric resistivity survey, however, failed to give evidence of major rock disturbances beneath nor in the vicinity of the ridges. Gravenor and Kupsch (1959) discovered very similar ridges from airphotos in the till plains of Alberta and Saskatchewan which they call "linear disintegration ridges"; these long narrow sharp ridges parallel to the ice flow formed during the recess of the ice sheet. Junctions with similar ridges from other directions are also described. Klebelsberg (1948) describes ridges of stagnant or receding ice masses as "Grundspaltenfuellungen" (ground crevasse fillings). None of the authors observed a broad hook at the end of these ridges; hook-like ends may be the result of shear in the ice whereby the ice west of the crevasse may have moved faster than the part east of the crevasse. They may also be thermal ice contraction cracks which were observed by Lachenbruch (1960) in the arctic regions. The unevenly readvancing ice lobe after some time of stagnation is here suggested to have caused the broad hooks. Mr. Jerry Johnson (1963) showed the author a drainage sketch map of an area north of Remington on which the smaller creeks align very well with the directions of the crevasse fillings and the shallow erosion troughs which were already mentioned under the chapter of negative relief lineaments.

Both the Remington and the Kentland mosaic disclose another light toned positive relief lineament which is quite different in appearance than the previously discussed light-colored features. A straight light-colored ridge extends from just northwest of Kentland to about 18 miles to the east southeast which is generally known among the local people as Sandy Ridge. Mr. Johnson told the author (1963) that this ridge ends in a parabolic dune. Gutschick (1961) in his study of the geologic structure of the area around the Newton County Stone Quarry saw Sandy Ridge from commercial airphotos as a light-colored lineament which he believes to be related to a possible bedrock fault hidden beneath glacial drift; this fault may have down dropped the mid-Paleozoic rocks as

much as 3000 feet south of the fault near the quarry. Sandy Ridge was also recognized by earlier soil surveyors of Newton County and shows clearly on the present soil map compiled by O. C. Rogers (1955) as an occasionally interrupted narrow sand ridge. The soil name is Ade, loamy fine sand, undulating phase 2-5 percent slope on top of Sandy Ridge. From the air the lineament is a long narrow line resembling an old railroad bed with a sharp edge terminating the ridge to the south but a much less distinct boundary toward the till to the north. The azimuth of the ridge changes very little along its entire length: N. 70 W. just one-half mile south of Newton County Stone Quarry, and about N. 76 W. south of Remington. A few minor breaks offset the ridge with loops a few hundred feet to the north. Illustration 2 clearly shows part of Sandy Ridge south of Remington in Benton County. On the ground Sandy Ridge is a low and inconspicuous ridge.

Three auger holes were drilled through the ridge at different points along the ridge, a profile one-half mile southeast of the Newton County Stone Quarry, one three miles west and three and one-half miles south of Remington, and the third hole four miles south of Remington in Benton County. All holes penetrated the ridge sediments down to the bluish gray till below. The grain size distribution of the sediments range from pure sand to loamy sand, to loamy sand and gravel. The auger holes southwest and south of Remington did not yield gravel until immediately above the till where the poorly rounded gravel appeared very loamy. The loamy gravel is water soaked and oxidized in all three holes. Illustration 3 compares the grain size distribution at different levels; it also compares the sorting against the ice crevasse fillings northeast of Remington and with two typical dune deposits, one from the area of Monon and the other from the Lake Michigan dune belt. The sand grains of both the ice crevasse fills, Sandy Ridge, and the dunes are of subangular to subround shape. Sandy Ridge diminishes its thickness toward the southeast from about 13 feet to about 6 feet near Remington. The till surface is also well-depressed underneath Sandy Ridge and also very well-compacted producing a small aquifer above the till which is too small for domestic consumption. Electric resistivity profiles across the ridge show a clear influence of the dry sand on top of the ridge and the small aquifer below near the till contact. The electric resistivity profile which is not pictured here fails to indicate a clear difference of the resistivity of the underlying bedrock north and south of the ridge. About a mile to the northeast a parallel linear feature may be visible which is so faint that the observer cannot always identify it on the mosaic. The azimuth is the same as Sandy Ridge; its length less than three miles and its outlines are blurred both to the north and to the south. Although it is not visible on the ground the Newton County Soil Map records it with the Foresman soil, fine sandy loam, 0-2 percent slope.

The following explanation is attempted for the origin of Sandy Ridge: renewal of movements along an old assumed fault underneath the ridge may have occurred under the uneven ice load of the receding ice sheet. The minor escarpment which was formed in the till caused cracking of the ice along the escarpment. Filling of the ice crevasse followed along the newly opened crack as coarser sediment below and finer above. The subsequent influence of strong dry winds off the receding ice sheet from the west northwest may have streamlined and drawn out the ridge to the southeast into a longitudinal dune which ends in a parabolic dune-like feature at its southeast end. The grain size distribution of the coarser fractions, .125 mm. and coarser, provide fair evidence for such a depositional sequence. The similarity of the azimuths of Sandy Ridge and the longitudinal dunes at Monon may be a coincidence. The grain rounding, subangular to subround, shows little difference from the rounding of a true dune sand of the Monon area because the grains were only little exposed to transportation from the nearby outwash flats.

CONCLUSIONS

Two different kinds of lineaments in glacial drift are observed in northwestern Indiana and an explanation of their origin is attempted.

1. Negative relief lineaments: they are dark-colored lines along shallow depressions which may reflect subsurface rock structures below thin ground moraines. More frequently, however, they reflect ice flow directions.

2. Positive relief lineaments: they are light-colored straight ridges of low elevation above the general till plain level. They may represent ice crevasse fillings caused by a stagnant or retreating ice sheet in the direction of the ice flow or old well-developed longitudinal dunes. Old bedrock faults revived by recent movements may also cause ice crevasse fillings along late glacial advances where the ice may crack over the escarpment and cause crevasse fillings. The very straight Sandy Ridge in the area of Kentland and Remington is believed to be the result of a fault-trapped crevasse filling which was modified by wind action. Lineaments caused by wind action only are not expected to reflect bedrock structures.

Both types of relief lineaments may be easily identified on airphotos on freshly plowed or tilled fields which were photographed with black-and-white aerial film and developed and printed with high contrast control.

BIBLIOGRAPHY

Barton, R. H., 1962, Differential isostatic rebound--Possible mechanism for fault reflection through glacial drift: Am. Assoc. Petroleum Geologists Bull., v. 46, no. 12, p. 2253-2254.

Dreimanis, A., 1953, Studies of friction cracks along the shores of Cirrus Lake and Kasakokwog Lake, Ontario: Am. Jour. Sci., v. 251, no. 11, p. 769-783.

Gravenor, C. P. and Kupsch, W. O., 1959, Ice-desintegration features in western Canada: Jour. Geology, v. 67, no. 1, p. 48-64.

Gutschick, R. C., 1961, The Kentland structural anomaly, Indiana: Geol. Soc. America Guidebook for Field Trips, Cincinnati Meeting, Field Trip No. 2, p. 12-17.

Klebelsberg, R. V., 1948, Handbuch der Gletscherkunde und Glazialgeologie, v. 1, p. 99.

Kupsch, W. O. and Wild, J., 1958, Lineaments in Avonlea area, Saskatchewan: Am. Assoc. Petroleum Geologists Bull., v. 42, no. 1, p. 127-134.

Lachenbruch, A., 1960, Thermal contraction cracks in ice wedges in permafrost: U. S. Geol. Survey Prof. Paper 400-B, p. 127-134.

Lattman, L. H., 1958, Technique of mapping geologic fracture traces and lineaments on aerial photographs: Photogrammetric Engineering, v. 24, no. 2, p. 568-576.

______ and Matzke, R. H., 1961, Geological significance of fracture traces: Photogrammetric Engineering, v. 27, no. 3, p. 435-438.

Leighton, M. M., 1959, Stagnancy of the Illinoian glacial lobe east of the Illinois and Mississippi Rivers: Jour. Geology, v. 67, no. 3, p. 337-344.

McGrain, P., 1950, Thickness of glacial drift in north central Indiana: Indiana Flood Control and Water Resources Commission, Circ. 1.

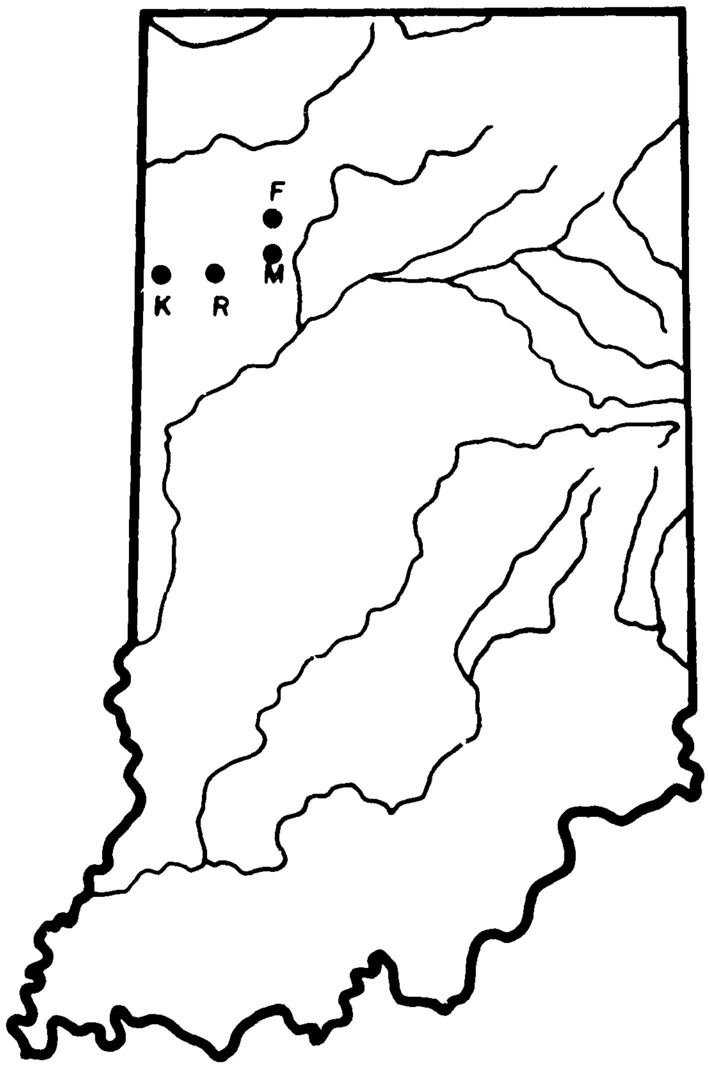
Odum, H. T., 1952, The Carolina Bays and a Pleistocene weather map: Am. Jour. Sci., v. 250, p. 263-270.

Rogers, O. C., et al., 1955, Soil Survey of Newton County, Indiana: U. S. Dept. Agriculture Soil Conservation Serv. and Purdue Univ. Agricultural Exp. Sta., Series 1941, no. 14.

Wayne, W. J., 1963, Pleistocene formations in Indiana: Ind. Dept. Conservation, Geol. Survey, Bull. 25, p. 1-85.

Winkler, E. M., 1962, Relationship of airphoto tone control and moisture content in glacial soils: Proc. Second Symposium on Remote Sensing of Environment, Inst. of Sci. and Tech., Univ. of Michigan, 15 October 1962.

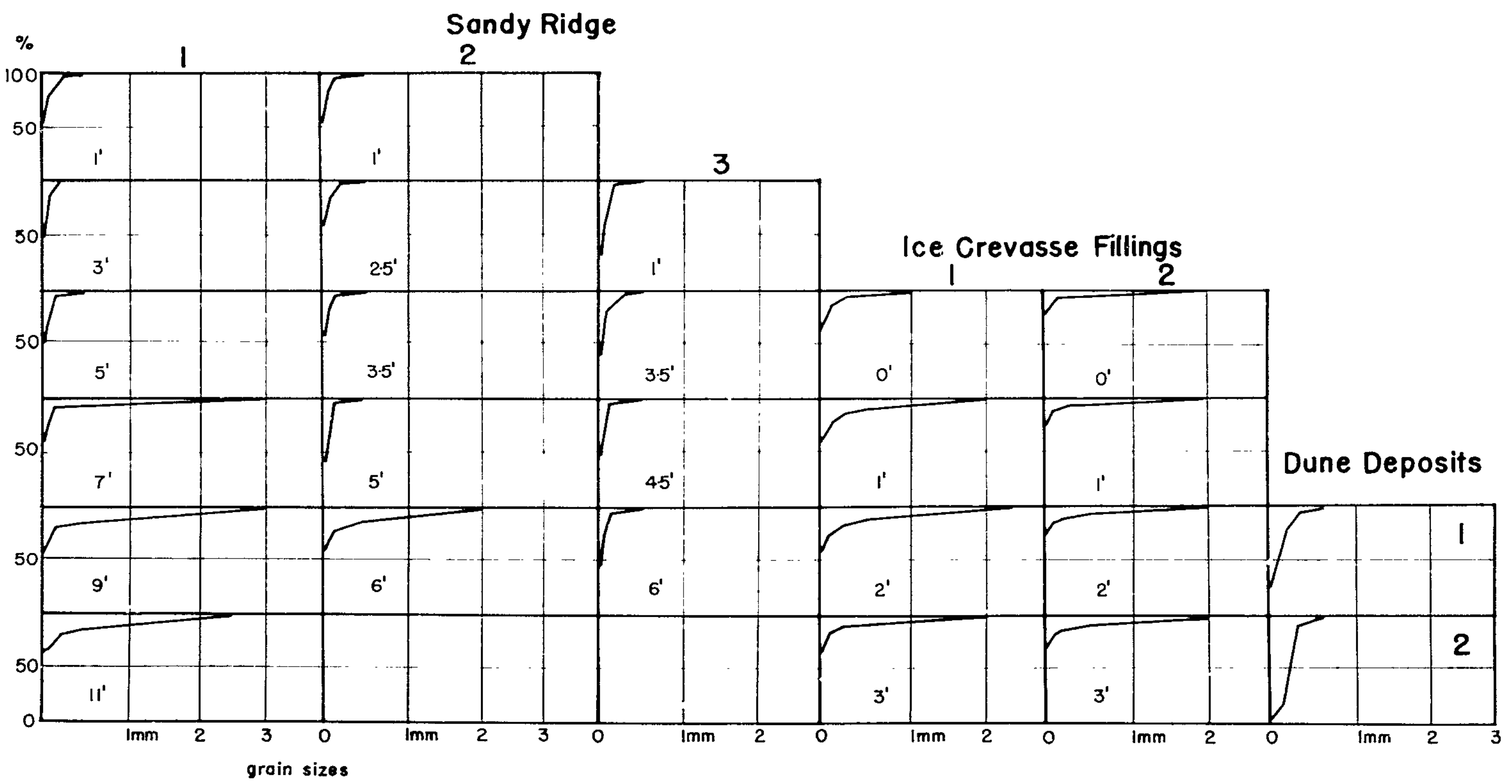
Zumberge, J. H., 1960, Correlation of Wisconsin drifts in Illinois, Indiana, Michigan, and Ohio: Geol. Soc. America Bull., v. 71, no. 8, p. 1177-1188.



Sketch map of Indiana showing locations of airphoto mosaics. F - Francesville; M - Monon; R - Remington; K - Kentland.

Illustration 1. Monon mosaic. 1 - Monon Crushed Stone Quarry; 2 - Light reflections off the glossy mosaics, no real lineaments; 3 - Longitudinal dune; 4 - Shallow parabolic dune; 5 - Parabolic dune enclosed by longitudinal dunes, protected by vegetation.

Illustration 2. Remington mosaic. 1 - Positive relief lineament (ice crevasse fillings); 2 - Carpenter's Creek in Fountain Park, a structure controlled subsequent stream; 3 - Dark northwest-southeast lineament by late ice advance; drainage follows
4 - Dark northeast-southwest lineament of earlier ice advance from Saginaw ice lobe; 5 - Sandy Ridge; insert, to right below, continues to the northwest of mosaic.



Sandy Ridge
1
2
3
Ice Crevasse Fillings
1
2
Dune Deposits
1
2
%
100
50
0
1'
3'
5'
7'
9'
11'
1'
2.5'
3.5'
5'
6'
1'
3.5'
4.5'
6'
0'
1'
2'
3'
0'
1'
2'
3'
0
1mm
2
3
grain sizes